

# Assessment of left ventricular performance during percutaneous transluminal coronary angioplasty: a study by intravenous digital subtraction ventriculography

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**ABSTRACT** Left ventricular performance during percutaneous transluminal coronary angioplasty was assessed in 52 patients by intravenous digital subtraction ventriculography. After injection of contrast into the right atrium ventriculograms were obtained before and during balloon inflation. In 37 patients they were also obtained after the procedure. A 12 lead electrocardiogram was monitored throughout. During balloon inflation the left ventricular ejection fraction fell (from 73% to 57%) in all but one patient; the decreases in patients with single vessel or multivessel disease were similar. The fall in left ventricular ejection fraction during percutaneous transluminal coronary angioplasty of the left anterior descending artery (19%) was significantly greater than that during balloon inflation in the right coronary (10%) or circumflex (8%) coronary arteries. It also reduced anterobasal, anterior, and apical segmental shortening while right coronary percutaneous transluminal coronary angioplasty affected inferior and apical segments. In 33 (63%) patients the ST segment was altered during balloon inflation. The fall in left ventricular ejection fraction correlated significantly with the magnitude of both ST segment elevation ( $r = 0.637$ ) and ST depression ( $r = 0.396$ ). Left ventricular ejection fraction and regional wall motion returned to baseline values after the procedure.

Balloon inflation during percutaneous transluminal coronary angioplasty produces considerable abnormalities of global and regional left ventricular performance and this indicates the presence of myocardial ischaemia, which may not be apparent on electrocardiographic monitoring. Intravenous digital subtraction ventriculography is useful for monitoring left ventricular performance during controlled episodes of coronary occlusion produced by balloon inflation.

The emergence of percutaneous transluminal coronary angioplasty has provided an attractive setting in which to study left ventricular performance during short, controlled and reversible episodes of myocardial ischaemia.<sup>1</sup> Earlier studies used either M mode<sup>2,3</sup> or cross sectional echocardiography,<sup>4-6</sup> or direct cine left ventriculography.<sup>7-9</sup> These studies demonstrated the effect of balloon occlusion on global and regional left ventricular function. But both these techniques

have limitations during percutaneous transluminal coronary angioplasty.

Echocardiography, although ideal for repeated or continuous studies, is dependent on patient suitability and operator expertise. The supine position of the patient on a catheter laboratory table is not always ideal for producing acceptable echocardiograms.<sup>5,6</sup> Direct cine left ventriculography requires the insertion of a second arterial catheter, which makes the percutaneous transluminal coronary angioplasty procedure more invasive. Furthermore, a direct intraventricular injection of contrast medium frequently provokes ventricular extrasys-

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Accepted for publication 27 October 1987

toles which makes selection of cine frames for analysis of volume and wall motion difficult.<sup>10 11</sup>

For these reasons we have chosen to study left ventricular performance during percutaneous transluminal coronary angioplasty by intravenous digital subtraction left ventriculography. This technique produces diagnostic left ventriculograms from central venous contrast injection. Previous studies have demonstrated a high degree of correlation with direct cine ventriculograms when left ventricular volumes<sup>10 11</sup> and regional wall motion<sup>12 13</sup> measured by the two techniques were compared. Additional central venous cannulation does not significantly increase the invasiveness of percutaneous transluminal coronary angioplasty and contrast injection by this route is less likely to provoke extrasystoles.

We therefore report the first use of intravenous digital subtraction ventriculography in the examination of left ventricular contraction during percutaneous transluminal coronary angioplasty. We examined changes in global and regional left ventricular function in relation to alterations in the ST segment during electrocardiographic monitoring and we compared results in patients with single and multiple vessel coronary disease.

## Patients and methods

### PATIENTS

We studied 52 patients (45 men and seven women; mean age 53 (range 39–73)). All patients had stable but limiting angina despite medical treatment. Their regular medication, which included nitrates, calcium antagonists, and in 47 patients a  $\beta$  adrenergic blocking agent, was continued. No patient was taking digoxin and none had evidence of valve disease.

A resting electrocardiogram showed sinus rhythm in all cases with no evidence of bundle branch block. An electrocardiogram recorded during either spontaneous chest pain or a symptom limited treadmill exercise test had shown evidence of myocardial ischaemia in all patients as indicated by an alteration of at least 1 mm in the ST segment.

### CORONARY ANATOMY

Previous diagnostic coronary arteriography had demonstrated single vessel disease, defined as at least an estimated 70% reduction in luminal diameter, in 37 patients. Twelve of the remaining 15 patients had two vessel and three had three vessel disease. In all but one patient the right coronary artery was the dominant vessel, giving rise to the posterior descending artery.

### LESIONS ATTEMPTED

Percutaneous transluminal coronary angioplasty was attempted in the left anterior descending coronary

artery in 35 patients, the right coronary artery in seven, and the circumflex artery in eight patients (including the one patient with a dominant circumflex system). The remaining two patients had percutaneous transluminal coronary angioplasty to lesions in a diagonal artery. There were no occluded vessels and in all cases the target stenoses allowed antegrade flow of contrast. The lesions ranged in severity of luminal narrowing from 60% to 99% (mean 92%).

### PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY PROTOCOL

Patients were studied during elective single vessel angioplasty. Two hours before the procedure they were given oral premedication with a long acting nitrate, calcium antagonist, and either lorazepam or intramuscular papaveretum.

Angioplasty was performed via the femoral approach. An intravenous bolus of heparin (100 IU/kg) was given at the start of the procedure together with atropine (up to 1.2 mg) if the heart rate fell below 50 beats/min. We used non-ionic contrast medium, steerable guide wires, and balloon catheters with diameters varying from 2.5 to 3.5 mm. The number of balloon inflations ranged from 2 to 12 (mean 5). Inflation pressures ranged from 505 kPa (5 atm) for initial inflations, up to 1212 kPa (12 atm) (mean 808 kPa (8 atm)). Inflation lasted for 15–95 seconds (mean 57 seconds), and the mean total duration of inflation was 162 seconds.

### ELECTROCARDIOGRAPHIC MONITORING

Throughout the percutaneous transluminal coronary angioplasty procedure a standardised 12 lead electrocardiogram was monitored by a Seimens Elema Mingograf 804 and Mingograf 62 with a frequency response of 0.05–100 Hz. In order that the chest electrodes did not interfere with fluoroscopy during the procedure, we used Medicotest (A-50-VS, Cambmac) electrodes. The electrocardiogram was recorded at 25 mm/s immediately before and throughout each balloon inflation. Balloon inflation and deflation were marked on the electrocardiogram, which was recorded at the same paper speed until any changes had resolved.

### DIGITAL SUBTRACTION VENTRICULOGRAPHY

A 5 French pigtail catheter (Superflow, Cordis) was inserted via the femoral vein and the tip was positioned in the right atrium. For each ventriculogram, 40 ml of non-ionic contrast (Omnipaque, Nycomed; iodine concentration, 350 mg/ml) was injected at a rate of 17 ml/s. We allowed seven seconds after the onset of contrast injection for transit of the contrast bolus through the pulmonary

circulation and its subsequent arrival in the left ventricle. A digital ventriculogram was then acquired, in held inspiration, in a 30° right anterior oblique projection. Images were acquired at 12.5 frames per second on to a 256 × 256 pixel matrix using a Siemens Digitron connected online to a Siemens Elema Angioskop D imaging system. Acquisition times ranged from five to 10 seconds. The digital information was transferred on to hard computer disc and then to magnetic tape for subsequent recall and analysis. Ventriculograms were performed before the percutaneous transluminal coronary angioplasty procedure and after either 20 seconds (28 patients) or 60 seconds (24 patients) of balloon inflation. Thirty six patients were studied during the third balloon inflation. Of the remainder, one was studied during the second inflation, eight during the fourth, three during each of the fifth and sixth, and one during the eighth balloon inflation.

A third ventriculogram was performed in 37 patients immediately after the percutaneous transluminal coronary angioplasty was completed. In all cases, this was undertaken within 15 minutes of the ventriculogram acquired during balloon inflation and when the electrocardiogram had returned to normal.

#### DATA ANALYSIS

##### Electrocardiography

The deviation of the ST segment was measured 80 ms after the J point, a change of at least 1 mm being regarded as important. Leads V2–V5 were regarded as representing the left anterior descending coronary territory while leads II, III, and aVF were taken to

reflect the distribution of the right coronary artery. The territory of the circumflex artery was represented by leads I, aVL, and V6. The maximum ST alteration in any lead was recorded.

##### Ventriculograms

Each digital acquisition was recalled on to hard disc and reviewed to identify the end diastolic and end systolic frames that were suitable for analysis. Extrasystoles were excluded. End diastolic frames were identified by an R wave marker. The subsequent end systolic frame was identified visually as that frame with minimum left ventricular dimensions. Left ventricular volume was identified by an area-length method<sup>14</sup> and ejection fraction was derived.

For analysis of left ventricular wall motion we used a method that does not make assumptions about left ventricular geometry.<sup>15</sup> Unlike the centre-line method it does not require identification of the apex of the ventricle. In this study, this was an advantage because location of the left ventricular apex is difficult in patients with coronary disease, who are likely to have segmental contraction abnormalities, especially during percutaneous transluminal coronary angioplasty. End diastolic and end systolic frames were outlined by hand. We took care to draw the end systolic outline outside the papillary muscles. We used a computer program to translate the two outlines so that the centres of each aortic valve plane could be superimposed. A series of radii were then drawn every 8°, from the edge of the aortic valve plane of the end diastolic frame, in a clockwise sweep, to the opposite aortic plane edge. These radii had their centre at the geometric centre of gravity of the

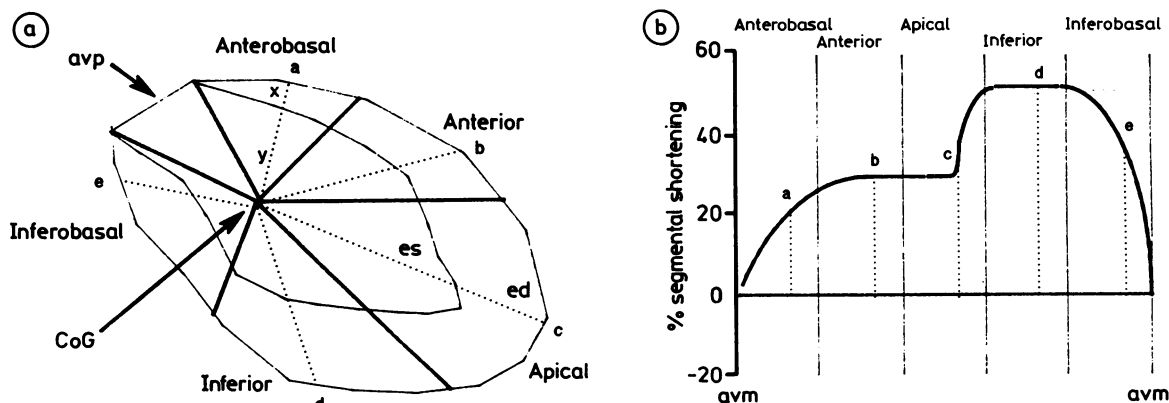


Fig 1 Schematic representation of method to quantify regional left ventricular contraction. Sample radii (a–e) are shown for each left ventricular segment. Percentage segmental shortening (for example radius a) =  $x/x + y \times 100$ . CoG, centre of gravity of end systolic frame; avp, aortic valve plane; es, end systolic outline; ed, end diastolic outline. Percentage shortening for each radius plotted on a wall motion graph. avm, aortic valve margin.

Table 1 Left ventricular segmental shortening (percentage regional shortening (SD)) before percutaneous transluminal coronary angioplasty (52 patients)

LV segment	Regional shortening	Normal range
Anterobasal	35 (12)	28–40
Anterior	36 (13)	30–45
Apical	46 (16)	42–62
Inferior	47 (13)	40–58
Inferobasal	8 (13)	0–20

end systolic frame. We calculated the percentage shortening of each radius, from the end diastolic to the end systolic outline (fig 1a). This was then represented as a point on a wall motion plot, showing percentage shortening for each radius in turn, in a clockwise sequence beginning at the upper limit of the aortic valve plane. The left ventricular perimeter was divided into five equal radial segments to represent the anterobasal, anterior, apical, inferior, and inferobasal left ventricular regions. The percentage shortening of the radii in each of these five segments was averaged to quantify regional contraction (fig 1b).

#### STATISTICAL ANALYSIS

We used Student's paired *t* tests to examine left ventricular ejection fraction and regional shortening before, during, and after percutaneous transluminal coronary angioplasty. We used unpaired *t* tests to compare patient subgroups with lesions of the left anterior descending, right, or circumflex arteries and with single or multivessel disease. Simple correlation and regression analysis was used to relate changes in left ventricular ejection fraction to ST segment deviation.

The study was approved by the ethics committee of the National Heart and Chest Hospitals and all patients gave written, informed consent.

#### Results

##### PRACTICAL CONSIDERATIONS

We obtained ventriculograms that were suitable for

Table 2 Left ventricular ejection fraction (% (SD)) in patients undergoing percutaneous transluminal coronary angioplasty (PTCA) of the left anterior descending, right, and circumflex coronary arteries

Vessel dilated (cases)	Before PTCA	During PTCA	<i>p</i>
LAD (35)	74 (8)	55 (13)	< 0.001
RCA (7)	70 (14)	60 (14)	< 0.01
LCX (8)	69 (10)	61 (12)	< 0.01

LAD, left anterior descending; RCA, right coronary artery; LCX, circumflex.

analysis from all 52 patients. Patients were required to hold inspiration for up to 10 seconds to allow data acquisition during balloon inflation, but this was not difficult.

The interval allowed for pulmonary transit of the contrast bolus was variable. In some patients, an interval of seven seconds after right atrial contrast injection was not sufficient for the arrival of contrast in the left ventricle, and so the first 30 to 50 frames of the ventriculogram were contrast free. In others, contrast was already clearing from the left ventricle when acquisition was started five seconds after injection. The duration of pulmonary transit was not related to either the heart rate or the degree of any pre-existing ventricular dysfunction.

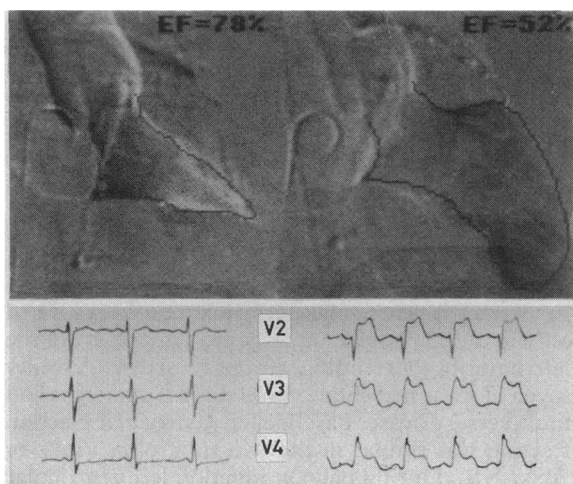
##### COMPLICATIONS

There was ectopic activity during ventriculography in three patients in the study undertaken before percutaneous transluminal coronary angioplasty (supraventricular in two, ventricular in one) and in six others during balloon inflation (supraventricular in three, ventricular in three). In all these cases the extrasystoles were single and did not interfere with data analysis. Transient atrial fibrillation occurred in one patient immediately after injection of contrast for the pre-angioplasty ventriculogram. This was asymptomatic and did not recur during subsequent ventriculograms. Because this arrhythmia was short lived, it did not affect ventriculographic analysis.

Table 3 Percentage shortening (mean (SD)) of left ventricular segments before and during percutaneous transluminal coronary angioplasty in patients undergoing dilatation of the left anterior descending, right, or circumflex coronary artery

LV segment	LAD (35 patients)			RCA (7 patients)			LCX (8 patients)		
	Before PTCA	During PTCA	<i>p</i>	Before PTCA	During PTCA	<i>p</i>	Before PTCA	During PTCA	<i>p</i>
AB	37 (10)	28 (15)	< 0.002	33 (14)	30 (12)	NS	27 (15)	22 (14)	NS
A	39 (11)	13 (18)	< 0.001	38 (14)	34 (12)	NS	25 (18)	19 (25)	NS
AP	50 (14)	14 (19)	< 0.001	44 (19)	38 (20)	< 0.02	37 (20)	27 (26)	NS
I	48 (13)	46 (14)	NS	43 (17)	24 (18)	< 0.01	52 (11)	41 (14)	NS
IB	8 (13)	25 (17)	< 0.001	7 (11)	0 (14)	NS	10 (18)	18 (20)	NS

AB, anterobasal; A, anterior; AP, apical; I, inferior; IB, inferobasal; LV, left ventricular; LAD, left anterior descending; RCA, right coronary artery; LCX, circumflex.



**Fig 2** End systolic outline of the left ventricle and electrocardiogram before (left) and during (right) balloon inflation in the left anterior descending coronary artery. Pronounced anteroapical akinesis was apparent during balloon occlusion associated with ST segment elevation in the leads reflecting activity in the anterior myocardium. EF, ejection fraction.

#### LEFT VENTRICULAR PERFORMANCE BEFORE PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY (TABLE 1)

The mean left ventricular ejection fraction of all 52 patients was 73% (range 51–90%). Table 1 shows the regional wall motion for each of the five left ventricular segments assessed and the normal range of regional shortening in 10 patients with normal left ventricular contraction.

#### EFFECT OF BALLOON INFLATION ON LEFT VENTRICULAR PERFORMANCE

##### *Effect on left ventricular ejection fraction*

During balloon inflation ejection fraction decreased in all but one patient. The mean fall in ejection fraction was from 73% to 57% ( $p < 0.001$ ). The decrease in left ventricular ejection fraction was no different in the 36 patients studied during the third balloon inflation (74% to 57%) than in the eight studied during the fourth inflation (70% to 59%) and the seven patients studied during subsequent inflations (72% to 56%).

Table 2 shows the effect on left ventricular ejection fraction of dilatation of the left anterior descending, right, and circumflex coronary arteries. The fall (19%) in left ventricular ejection fraction during dilatation of the left anterior descending artery was larger than that during balloon occlusion of the right (10%,  $p < 0.05$ ) and circumflex coronary arteries (8%,  $p < 0.01$ ).

#### EFFECT ON LEFT VENTRICULAR WALL MOTION (TABLE 3)

To assess the effect of balloon occlusion on segmental left ventricular performance, patients were grouped according to the site of the treated stenosis.

##### *Dilatation of the left anterior descending coronary artery (35 patients, fig 2)*

During balloon inflation regional shortening in the anterobasal, anterior, and apical left ventricular segments decreased. There was no change in inferior segmental contraction but inferobasal contraction increased.

##### *Dilatation of the right coronary artery (seven patients, fig 3)*

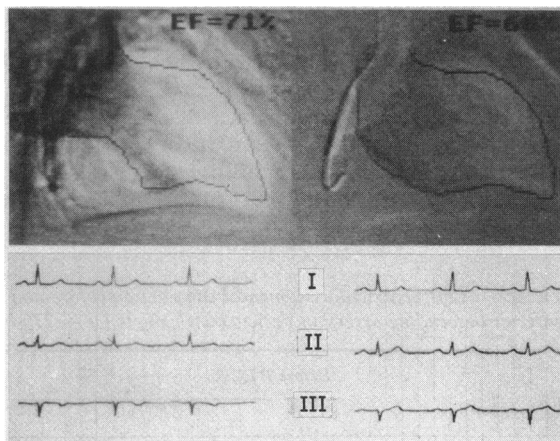
Balloon occlusion resulted in a fall in both inferior and apical contraction. There was no significant change in inferobasal, anterior, or anterobasal contraction.

##### *Dilatation of the circumflex coronary artery (eight patients)*

Balloon inflation did not produce significant changes in any left ventricular segment examined.

##### *Dilatation of the diagonal vessel (two patients)*

In these two patients balloon inflation produced falls in left ventricular ejection fraction of from 73% to 59%. The left ventricular segments affected were the anterior and apical regions, in which contraction was reduced from 35% and 40% to 14% and 5% respectively. Inferior contraction did not change



**Fig 3** End systolic outline of the left ventricle and electrocardiogram before (left) and during (right) balloon inflation of the right coronary artery. Inferobasal akinesis was in association with normalisation of a previously inverted T wave in lead III only. EF, ejection fraction.

appreciably but inferobasal contraction increased from 3% to 25%.

#### ELECTROCARDIOGRAPHIC CHANGES

Although left ventricular ejection fraction fell during balloon inflation in 51 of the 52 patients, ST segment altered ( $>1$  mm) in only 33 (63%). In thirty two patients ST elevation developed (mean 3.9 mm, range 1–9 mm). In all cases this occurred in leads coinciding with the myocardial territory supplied by the occluded artery. In 25 patients ST depression (mean 1.9 mm, range 1–3 mm) developed while in 24 patients both ST elevation and depression were seen.

Left ventricular ejection fraction before percutaneous transluminal coronary angioplasty was similar in the 32 patients in whom ST elevation subsequently developed during balloon inflation and the 20 in whom it did not (74% *vs* 72% respectively, NS). During balloon inflation, however, the fall in left ventricular ejection fraction was more pronounced in those patients with ST elevation (21%) than in those without (9%,  $p < 0.001$ ). Furthermore, there was a significant positive correlation between the magnitude of ST segment elevation during balloon inflation and the reduction in left ventricular ejection fraction ( $r = 0.637$ ,  $p < 0.001$ ). Similarly, there was a positive though less strong correlation between the degree of ST segment depression and the fall in left ventricular ejection fraction ( $r = 0.396$ ,  $p < 0.01$ ).

#### SINGLE VS MULTIVESSEL DISEASE

##### *Global left ventricular performance*

The 37 patients with single vessel disease had a higher control left ventricular ejection fraction than the 15 patients with multivessel disease (75% *vs* 68% respectively,  $p < 0.02$ ). During angioplasty left ventricular ejection fraction fell to 59% ( $p < 0.001$ ) in those with single vessel disease and to 51% ( $p < 0.001$ ) in those with multivessel disease. Although left ventricular ejection fraction during inflation was lower in those patients with multivessel disease ( $p < 0.05$ ), the size of the fall in both groups was almost the same (16% *vs* 17% respectively, NS).

##### *Electrocardiographic changes*

The size of ST segment elevation during balloon inflation in the 37 patients with single vessel disease (2.4 mm) was no different from that in the remaining 15 patients with multivessel disease (2.3 mm, NS). Similarly, the degree of ST segment depression was no different in these two groups (0.8 mm *vs* 1.2 mm respectively, NS).

##### *Regional left ventricular performance (35 patients, table 4)*

Regional left ventricular performance was examined only in the 35 patients undergoing angioplasty of the left anterior descending coronary artery. Twenty seven of these had single vessel disease and eight had multivessel disease. Baseline left ventricular ejection fraction was similar in the two subgroups (76% *vs* 70%, NS). During balloon inflation left ventricular ejection fraction fell to 57% in those with single vessel disease and to 48% in those with multivessel disease. The size of the fall was similar in these two subgroups (19% *vs* 22%, NS).

Similarly, there was no difference between these two subgroups in the degree of ST elevation (3.2 mm *vs* 3.0 mm, NS) and ST depression (1.0 mm *vs* 1.0 mm, NS).

There was no difference in regional left ventricular contraction either before or during balloon inflation in the left anterior descending coronary artery between patients with single or multivessel disease (table 4).

##### *Left ventricular performance after percutaneous transluminal coronary angioplasty (37 patients, table 5)*

Thirty seven patients underwent intravenous digital subtraction ventriculography after percutaneous transluminal coronary angioplasty. In all cases the accompanying electrocardiogram had returned to its control state and ventriculography was performed within 15 minutes of the end of the percutaneous transluminal coronary angioplasty procedure.

Both left ventricular ejection fraction and regional left ventricular wall motion returned to the control

Table 4 Left ventricular segmental contraction before and during percutaneous transluminal coronary angioplasty of the left anterior descending artery in patients with single ( $n = 27$ ) or multivessel disease ( $n = 8$ )

LV segment	Before PTCA			During PTCA		
	SVD	MVD	<i>p</i>	SVD	MVD	<i>p</i>
Anterobasal	37 (10)	36 (11)	NS	28 (15)	30 (15)	NS
Anterior	40 (10)	36 (13)	NS	15 (18)	8 (16)	NS
Apical	53 (10)	39 (20)	NS	17 (19)	3 (13)	NS
Inferior	48 (14)	47 (7)	NS	47 (14)	43 (12)	NS
Inferobasal	7 (12)	13 (14)	NS	25 (20)	24 (7)	NS

Values given are mean (SD) percentage shortening. SVD, single vessel disease; MVD, multivessel disease; LV, left ventricular.

Table 5 Left ventricular ejection fraction and segmental wall motion before and after percutaneous transluminal coronary angioplasty (37 patients)

	Before PTCA	After PTCA	p
LV ejection fraction	74 (9)	73 (8)	NS
LV regional shortening:			
Anterobasal	37 (11)	35 (10)	NS
Anterior	38 (13)	36 (16)	NS
Apical	48 (16)	45 (20)	NS
Inferior	49 (13)	49 (17)	NS
Inferobasal	8 (15)	9 (15)	NS

Values are mean percentage (SD). LV, left ventricular.

value after the procedure. Fifteen patients were not studied after percutaneous transluminal coronary angioplasty. In nine cases the procedure was complicated by protracted coronary occlusion. This had resulted in a prolonged episode of myocardial ischaemia associated with considerable ST segment elevation. It was felt inappropriate to study these patients further. In three patients the angioplasty procedure itself had become protracted and had already used a large volume of contrast media. The addition of a third ventriculogram incorporating another 40 ml of contrast was deemed unwise. The three remaining patients not studied after percutaneous transluminal coronary angioplasty were recruited into another study that required them to undergo ventriculography during another balloon inflation. Ethical approval for the present study did not extend to four ventriculograms and thus the post-percutaneous transluminal coronary angioplasty study in these patients was waived.

## Discussion

We report the first use of intravenous digital subtraction ventriculography in the assessment of left ventricular performance during coronary angioplasty. The validity of intravenous digital subtraction angiography has been established in studies that compared it with direct cine left ventriculography.<sup>10-12</sup> Correlation between the two techniques, in terms of both left ventricular volumes and ejection fraction, was good and digital subtraction angiography provoked fewer extrasystoles. Importantly, the degree of correlation between these techniques persisted in patients with impaired left ventricular function.<sup>16,17</sup> This is particularly relevant in patients undergoing percutaneous transluminal coronary angioplasty in whom left ventricular ejection fraction may fall profoundly during balloon inflation. Digital subtraction analysis and cine left ventriculograms gave corresponding assessments of regional left ventricular performance.<sup>11-13</sup>

In addition to validating the technique other studies have capitalised on the less invasive nature of

intravenous digital subtraction analysis. Thus the technique has been used during exercise<sup>18</sup> and atrial pacing<sup>19</sup> in the investigation of patients with coronary disease, and as an outpatient assessment of left ventricular function.<sup>20</sup>

We found that this technique was suitable for the assessment of left ventricular performance during percutaneous transluminal coronary angioplasty. Although respiratory motion can often degrade the results of mask subtraction, this did not prove to be a problem, even during balloon coronary occlusion.

We used a non-ionic contrast agent (Omnipaque) for ventriculography. During intravenous digital subtraction angiography, passage of the contrast bolus through the pulmonary circulation can cause the patient to cough and this can interfere with image analysis. The risk of this happening is reduced by use of a non-ionic contrast and none of our 52 patients was affected. The use of non-ionic contrast enabled us to perform three ventriculograms in most patients. With conventional contrast agents such an amount of sodium, together with that required for the percutaneous transluminal coronary angioplasty procedure itself, might impose an appreciable ionic load.

The reduction in ectopic activity during intravenous digital subtraction angiography proved to be a distinct advantage; only nine of our 52 patients had extrasystoles. This is lower than the frequency reported by Norris *et al* in a study of 26 patients in whom nine developed extrasystoles during intravenous ventriculography.<sup>10</sup> This increased incidence may be explained by the use of an end hole rather than a multiple side hole catheter (either a Cournand or a Zucker). This would produce a more forceful single jet that is more likely to stimulate extrasystoles. Catheter recoil is also minimised and contrast mixing is improved with a pigtail catheter. There were few complications in our patients and only one of them developed transient atrial fibrillation.

Of the nine patients who developed extrasystoles in our study, these were supraventricular in five, and presumably directly related to atrial contrast injection. This finding accords with those of other workers who also found that atrial extrasystoles were more common than ventricular ones.<sup>10</sup>

Intravenous digital subtraction ventriculography did not significantly increase the invasiveness of the percutaneous transluminal coronary angioplasty. We routinely insert a femoral venous sheath during percutaneous transluminal coronary angioplasty in order to provide a route for intravenous administration of drugs or a temporary pacing catheter if required. The use of this sheath to insert a central venous pigtail catheter for contrast injection was preferable to cannulation of another peripheral artery, which would have been required if direct cine

left ventriculography had been undertaken during percutaneous transluminal coronary angioplasty.

#### EFFECT OF BALLOON INFLATION ON GLOBAL LEFT VENTRICULAR PERFORMANCE

During balloon inflation in our 52 patients mean left ventricular ejection fraction fell from 73% to 57%. This is similar to the experience of other workers. Serruys *et al* noted a fall from 62% to 48% after 50 seconds of balloon occlusion.<sup>7</sup> Our fall in left ventricular ejection fraction in the whole group (16%) is similar to the decrease that Serruys *et al* reported (14%). Doorey *et al* noted a similar fall from 66% to 44% in patients not pretreated with nitrates.<sup>8</sup> After the administration of a nitrate left ventricular ejection fraction fell to only 49%. Bertrand *et al* noted a fall from 73% to 45%<sup>9</sup> which accords with our findings.

Previous studies did not examine global left ventricular performance in patients undergoing percutaneous transluminal coronary angioplasty of the circumflex coronary artery or right coronary artery. We showed that the reduction in left ventricular ejection fraction (19%) was significantly more pronounced during angioplasty of the left anterior descending coronary artery than during either balloon inflation in the right (10%) or circumflex (8%) arteries. This is compatible with our knowledge of the coronary circulation, where the left anterior descending coronary artery supplies most of the anterior left ventricular wall, septum, and apex. The small decrease in ejection fraction during angioplasty of the circumflex artery may relate to the 30° right anterior oblique projection that we used for image acquisition. This projection does not show the profile of the lateral wall of the heart and therefore abnormalities in this region may not be appreciated.

#### EFFECT OF BALLOON OCCLUSION ON REGIONAL LEFT VENTRICULAR FUNCTION

We found that balloon inflation in the left anterior descending artery predictably produced deterioration in the anterobasal, anterior, and apical segments. These findings accord with those of other workers. Doorey *et al* also demonstrated inferoapical dysfunction and noted that only anterobasal and inferobasal segmental shortening did not show a significant decrease in function.<sup>8</sup> Wohlgeleirnter *et al* similarly showed inferoapical dysfunction in addition to apical and septal changes.<sup>6</sup>

Interestingly, we also showed an appreciable increase in inferobasal contraction in this group. This feature has not been seen by others.<sup>3,6</sup> Doorey *et al*, however, noted an increase in shortening of the inferoapical and mid inferior segment during angioplasty of the left anterior descending coronary artery

after the administration of glyceryl trinitrate compared with the shortening seen without glyceryl trinitrate.<sup>8</sup> All our patients routinely received a nitrate as part of their premedication and so we were not able to test the specific role of nitrates in improving segmental function distant to the ischaemic territory.

Few workers have examined the effects of balloon inflation during percutaneous transluminal coronary angioplasty of the right coronary artery. Alam *et al* demonstrated that during such a procedure abnormal wall motion was most noticeable posteriorly<sup>3</sup> while Hauser *et al* demonstrated deterioration in inferior contraction.<sup>5</sup> Visser *et al* studied only two patients during occlusion of the right coronary artery and showed that the resulting degree of left ventricular dysfunction was less pronounced than that during balloon inflation in the left anterior descending coronary artery.<sup>4</sup> This suggests that occlusion of the right coronary artery may have a less detrimental effect on global and regional left ventricular performance than occlusion of the left anterior descending coronary artery. Our results support this view because we found that left ventricular ejection fraction fell to a greater extent during balloon inflation in the left anterior descending coronary artery than during balloon inflation in the right coronary artery.

The effect of balloon occlusion of the circumflex artery on regional left ventricular performance has only been reported in two studies. Alam *et al* observed the effect of combined occlusion of both the left anterior descending and circumflex coronary arteries in one patient who developed reduced systolic excursion of both the septum and posterior walls.<sup>3</sup> Hauser *et al* showed no change in wall motion on cross sectional echocardiography during occlusion of the circumflex artery in one patient.<sup>5</sup> Our data on eight patients who showed no significant change in any segments during balloon inflation in the circumflex artery suggest that it is likely that lateral left ventricular segments rendered ischaemic by such occlusion are less amenable to either echocardiographic or ventriculographic assessment than anteroapical or inferior segments rendered dysfunctional by occlusion of the left anterior descending or right coronary arteries. This would also account for left ventricular ejection fraction during occlusion of the circumflex artery falling only to 61%, significantly less than during percutaneous transluminal coronary angioplasty of the left anterior descending coronary artery. It may be that abnormal wall motion during circumflex percutaneous transluminal coronary angioplasty would have been detected better in a left anterior oblique projection which images the lateral left ventricular wall than in the right anterior oblique projection.



The effects of balloon occlusion of the diagonal artery on segmental wall motion have not been described before. We only studied two patients, and both of them showed anterior and apical dysfunction together with augmentation of inferobasal contraction.

#### ELECTROCARDIOGRAPHIC CHANGES

In 63% of patients in the present study the ST segment altered during balloon inflation. This frequency is similar to that reported by others.<sup>4,5,8</sup> Because 12 lead electrocardiographic monitoring improves the detection of ischaemia during percutaneous transluminal coronary angioplasty<sup>6</sup>, we used it in our study. Recent work has suggested that the ability to detect ischaemia during percutaneous transluminal coronary angioplasty may be enhanced by monitoring the intracoronary electrocardiogram recorded via the tip of the guide wire positioned distal to the coronary stenosis being treated.<sup>21</sup>

We have confirmed that the left ventricle can become dysfunctional in the absence of significant electrocardiographic change. We demonstrated, however, that the magnitude of global left ventricular ischaemia as manifest by a fall in left ventricular ejection fraction correlated significantly with the degree of ST segment elevation and to a lesser extent with ST segment depression. Thus ST segment alteration is an index of the degree of left ventricular ischaemia during percutaneous transluminal coronary angioplasty rather than merely an indicator of its presence.

#### PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY IN SINGLE VESSEL AND MULTIVESSEL DISEASE

Most previous studies have included only patients with single vessel disease. We found that up to 60 seconds of balloon inflation did not produce greater signs of ischaemia in patients with multivessel disease than in those with single vessel disease. The magnitude of ST segment change and the derangement of both global and regional left ventricular performance were no different in these two groups. It would be wrong to suggest that multivessel disease does not impose a greater ischaemic burden on the left ventricle than single vessel disease in patients undergoing percutaneous transluminal coronary angioplasty. The outcome after a complication during percutaneous transluminal coronary angioplasty in patients with multivessel disease is less favourable than that in patients with single vessel disease<sup>22</sup> and must reflect the consequences of coronary occlusion in the face of a reduced coronary reserve arising out of disease in other vessels. It may be that assessment of left ventricular performance after 60 seconds of

balloon occlusion may have been too short for significant differences between these two groups to become apparent.

#### LEFT VENTRICULAR PERFORMANCE AFTER PERCUTANEOUS TRANSLUMINAL CORONARY ANGIOPLASTY

We found that ejection fraction and regional wall motion returned to control values after the angioplasty procedure. This has been the experience of others who have similarly found no persistent dysfunction even after several long balloon inflations. Some workers found hypercontractility immediately after balloon deflation in segments that were dysfunctional during coronary occlusion.<sup>4,6</sup> These changes are apparent up to 20 seconds after balloon deflation but then rapidly return to normal. We did not see this overshoot phenomenon in regional wall motion. All patients were studied within 15 minutes of the completion of percutaneous transluminal coronary angioplasty but in no case did we perform the third ventriculogram within 20 seconds of the final balloon deflation.

#### CLINICAL IMPLICATIONS

We have shown that balloon inflation during percutaneous transluminal coronary angioplasty produces ischaemia manifest as profound but reversible abnormalities of global and regional left ventricular performance that may not be apparent with electrocardiographic monitoring. This is clinically relevant because it has been suggested that prolonged balloon inflation may reduce the rate of restenosis after successful percutaneous transluminal coronary angioplasty.<sup>23</sup> Some anxiety remains about the cumulative effect on the left ventricle of such prolonged episodes of coronary occlusion.<sup>24,25</sup> The examination of left ventricular performance by intravenous digital subtraction angiography during balloon inflation brings two benefits. In addition to providing valuable insight into the earliest effects of coronary occlusion, it may also allow a relatively non-invasive yet accurate assessment of techniques designed to limit myocardial ischaemia during percutaneous transluminal coronary angioplasty.

MSN is supported by the British Heart Foundation.

#### References

- 1 Serruys PW, Meester GT, eds. *Coronary angioplasty: a controlled model for ischaemia*. (Developments in cardiovascular medicine.) Dordrecht, The Netherlands: Martinus Nijhoff, 1986.
- 2 Das SK, Serruys PW, Van Den Brand M, *et al*. Acute echocardiographic changes during percutaneous transluminal coronary angioplasty and their relation-

- ship to coronary blood flow. *Journal of Cardiovascular Ultrasonography* 1983;2:269-71.
- 3 Alam M, Khaja F, Brymer J, Marzelli M, Goldstein S. Echocardiographic evaluation of left ventricular function during coronary artery angioplasty. *Am J Cardiol* 1986;57:20-5.
  - 4 Visser CA, David GK, Kan G, *et al.* Two-dimensional echocardiography during percutaneous transluminal coronary angioplasty. *Am Heart J* 1986;111:1035-41.
  - 5 Hauses AM, Gangadharan V, Ramos RG, Gordon S, Timmis GC. Sequence of mechanical, electrocardiographic and clinical effects of repeated coronary artery occlusion in human beings: echocardiographic observations during coronary angioplasty. *J Am Coll Cardiol* 1985;5:193-7.
  - 6 Wohlgeleit D, Cleman M, Highman HA, *et al.* Regional myocardial dysfunction during coronary angioplasty: evaluation by 2-dimensional echocardiography and 12 lead electrocardiography. *J Am Coll Cardiol* 1986;7:1245-54.
  - 7 Serruys PW, Wijns W, Van Den Brand M, *et al.* Left ventricular performance, regional blood flow, wall motion and lactate metabolism during transluminal angioplasty. *Circulation* 1984;70:25-36.
  - 8 Doorey AJ, Mehmel HC, Schwarz FX, Kubler W. Amelioration by nitroglycerin of left ventricular ischaemia induced by percutaneous transluminal coronary angioplasty: assessment by haemodynamic variables and left ventriculography. *J Am Coll Cardiol* 1984;6:267-74.
  - 9 Bertrand ME, Lablanche JM, Thieuleux FA. Changes in left ventricular relaxation during transient coronary occlusion in man [Abstract]. *Eur Heart J* 1983;4(suppl E):49.
  - 10 Norris SL, Slutsky RA, Mancini J, *et al.* Comparison of digital intravenous ventriculography with direct left ventriculography for quantitation of left ventricular volumes and ejection fractions. *Am J Cardiol* 1983;51:1399-403.
  - 11 Tobis J, Nacioglu O, Johnston WD, *et al.* Left ventricular imaging with digital subtraction angiography using intravenous contrast injection and fluoroscopic exposure levels. *Am Heart J* 1982;104:20-7.
  - 12 Goldberg HL, Borer JS, Moses JW, *et al.* Digital subtraction intravenous left ventricular angiography: comparison with conventional intraventricular angiography. *J Am Coll Cardiol* 1983;1:858-62.
  - 13 Kronenberg MW, Price RR, Smith CW, *et al.* Evaluation of left ventricular performance using digital subtraction angiography. *Am J Cardiol* 1983;51:837-42.
  - 14 Sandler H, Dodge HT. The use of single plane angiocardiograms for the calculation of left ventricular volume in man. *Am Heart J* 1968;75:325-34.
  - 15 Rickards A, Seabra-Gomes R, Thurston P. The assessment of regional abnormalities of the left ventricle by angiography. *Eur J Cardiol* 1977;5:167-82.
  - 16 Felix R, Eichstadt H, Kempter H, *et al.* A comparison of conventional ventriculography and digital subtraction ventriculography. *Clin Cardiol* 1983;6:265-76.
  - 17 Nissen SE, Booth D, Waters J, *et al.* Evaluation of left ventricular contractile pattern by intravenous digital subtraction ventriculography: comparison with cineangiography and assessment of interobserver variability. *Am J Cardiol* 1983;52:1293-8.
  - 18 Goldberg HL, Moses JW, Borer JS, *et al.* Exercise left ventriculography utilizing intravenous digital angiography. *J Am Coll Cardiol* 1983;2:1092-8.
  - 19 Johnson RA, Wasserman AG, Leibhoff RH, *et al.* Intravenous digital left ventriculography at rest and with atrial pacing as a screening procedure for coronary artery disease. *J Am Coll Cardiol* 1983;2:905-10.
  - 20 Greenbaum RA, Evans TR. Investigation of left ventricular function by digital subtraction angiography. *Br Heart J* 1984;51:163-7.
  - 21 Friedman PL, Shook TL, Kirshenbaum JM, Selwyn AP, Ganz P. Value of the intracoronary electrocardiogram to monitor myocardial ischaemia during percutaneous transluminal coronary angioplasty. *Circulation* 1986;74:1085-9.
  - 22 Bertrand ME, Marco J, Clavier F, *et al.* French percutaneous transluminal coronary angioplasty (PTCA) registry: four years experience [Abstract]. *J Am Coll Cardiol* 1986;7:21a.
  - 23 Kaltenbach M, Beyer J, Walter S, Klepzig H, Schmidts L. Prolonged application of pressure in transluminal coronary angioplasty. *Cathet Cardiovasc Diagn* 1984;10:213-9.
  - 24 Braunwald E, Kloner RA. The stunned myocardium: prolonged post-ischaemic ventricular dysfunction. *Circulation* 1982;66:1146-9.
  - 25 Geft IL, Fishbein MC, Ninomiya K, *et al.* Intermittent brief periods of ischaemia have a cumulative effect and may cause myocardial necrosis. *Circulation* 1982;66:1150-3.